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(71) Applicant *(for all designated States except US)*: **AOTI OPERATING COMPANY, INC.** [US/US]; Suite 207, 131 N.W. Hawthorne Avenue, Bend, OR 97701 (US).

(72) **Inventor; and**
(75) **Inventor/Applicant** *(for US only)*: **HIGGS, Victor** [GB/GB]; Accent Optical Technologies, Bio-Rad House, Maylands Avenue, Hemel Hempstead, Hertfordshire HP2 7TD (GB).

(74) **Agent: NOVAGRAAF PATENTS LIMITED**; The Crescent, 54 Blossom Street, York YO24 1AP (GB).

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(54) **Title:** DETECTION AND CLASSIFICATION OF MICRO-DEFECTS IN SEMI-CONDUCTORS

(57) **Abstract:** A method and apparatus for the detection and classification of defects in a silicon or semi-conductor structure, in particular using room temperature photoluminescence effects, is described. The method involves directing a high intensity beam of light at a surface of a sample of silicon or semi-conductor structure to be tested producing a photoluminescence image, producing a reflected light image, combining the information in the two images to detect, map and identify and/or characterise micro-defects in the silicon or semi-conductor structure.

DETECTION AND CLASSIFICATION OF MICRO-DEFECTS IN SEMI-CONDUCTORS

The invention relates to an apparatus and method for detection and classification of micro-defects in semiconductors or Silicon structures and particularly, but not exclusively, in Silicon on insulator wafers, polycrystalline Silicon, SiGe epilayers and like structures.

Rapidly shrinking device geometry and technological demand for high-performance circuits impose great demands to understand the physical phenomena related to microstructural properties of materials. Understanding these properties is necessary to facilitate the reduction in both, number of defects in the material and their degrading impact on IC performance and yield. All Silicon wafers contain certain level of defects whose nature and density depend upon crystal growth conditions and thermal history of the wafer in subsequent processing. Silicon on insulator fabrication techniques introduce their own category of defects, some being common and some being specific to the method of fabrication. To succeed in material improvement it is important to understand impact of process conditions on formation of defects, defects nature and their effects on device characteristics.

Defects are encountered in Silicon-on-insulator (SOI) materials fabricated using separation by implantation of oxygen (SIMOX). Wafers produced by this method have defect types specific defect type in SIMOX, such as Silicon bridges and Silicon inclusions in the buried oxide part of the structure (BOX). This invention can be used to locate and characterise the nature of these defects.

Polycrystalline Silicon contains grain boundaries (i.e. the boundary between two crystal regions of different orientation) which are physical defects. On the sample surface these defects will also have electrical activity affecting the behavior of the material. This invention can be used to locate and characterise the nature of these defects.

Developments in crystal growth have enabled the production of Silicon wafers free from dislocation. However, dislocation free wafers may not be able to remain this way after the wafers are subjected to high temperature processing. Defects formed within the device active region in the wafer and defects produced in the gate oxide generally degrade device performance, lead to yield losses and reliability problems. This invention can be used to locate and characterise the nature of these defects.

Transition metals, which are fast diffusers in Silicon, readily form deep levels, i.e. away from the valance or conduction band edge, and also lead to decoration of both point and extended defects which eventually lead to device failure. These transition metal impurities also form recombination centres and traps which can dramatically reduce carrier lifetime and can also act as dark current generation sites, i.e. in the absence of light, charge leakage will occur. Gettering techniques, where mechanical damage, such as abrasion, is typically undertaken in order to provide a damaged site, which effectively acts as a sponge soaking up impurities in the wafer, have been developed to remove transition metal impurities from the device active areas. It therefore follows that the aforementioned damage is deliberately targeted to an area in the wafer remote from the electrical device. Thus internal gettering techniques introduce defects in the Silicon substrate which attract unwanted impurities away from the device areas. Gettering sites need to be characterised to control their distribution for

different process conditions, a task which can be performed with the present invention.

Epitaxial Silicon, that is the deposited uppermost layers of Silicon, typically in the order of microns thick, has been used to overcome problems with as-grown CZ wafers. In other words, as the thickness in the epitaxial Silicon increases, given that this layer can be grown in a defect-free manner, it can be used as a site for the electric device without fear of contamination in the bulk wafer affecting the activity of the device. However it is not always possible to use an epitaxial layer of sufficient thickness for this activity and where the epitaxial layer is thin then defects in the bulk wafer can interfere with the electrical device. Moreover, epitaxial layers suffer from problems of metal contamination.

Several techniques already exist for the detection of defects in as-grown material, these include wet chemical etching in order to reveal flow pattern defects; light scattering topography where the topography of the surface wafer is examined using light to detect undulations which in turn are indicative of defects in the sub-structure; and transmission interference contrast microscopy where the transmission of light through the wafer is examined and the phase shift due to small path changes is used to image defects in the wafer. All of these techniques are used to measure the physical presence of defects in the wafer. However they do not measure the electrical properties of the defects and moreover in some cases they are destructive. Accordingly, as techniques for determining the structural integrity of a wafer they are lacking in terms of the information they provide and moreover they can be positively destructive.

Photoluminescence (PL) spectroscopy is a very sensitive technique for investigating both intrinsic and extrinsic electronic transitions at impurities and defects in semiconductors. When Silicon is excited at low temperatures with laser irradiation above the band-gap of the material, electron hole pairs are produced. These carriers can recombine in various different ways, some of which give rise to luminescence. The electron hole pairs formed at low temperature can be trapped at impurities in Silicon and they emit photons characteristic of this interaction, thereby giving impurity specific information in the photoluminescence spectra. There are a significant number of applications of PL spectroscopy to Silicon including characterization of Silicon after different processing steps, characteristic of device fabrication for example implantation, oxidation, plasma etching, the detection of point defect complexes and the presence of dislocations. One of the most important applications includes the non-destructive measurement of shallow donors and acceptors such as arsenic, boron and phosphorous. Notably, this technique enables the measurement of the concentration of these shallow donors and acceptors. However, in conventional applications in order to obtain this spectral information and unambiguous chemical identification of the optical centres, measurements need to be carried out at liquid helium temperatures. It is known throughout the industry that at room temperature the PL signal is significantly weakened and very little useful spectral information can be obtained.

International patent application WO97/09649 describes a non-destructive technique which makes practical the detection of electrically active defects in semi-conductor structures based on room temperature PL. The patent application discloses a PL technique which has industrial application in that it enables the image to be produced within minutes and which has a further added advantage in producing micro imaging of small individual defects particularly

near to the surface of the wafer, where the device is fabricated.

The technique provides information concerning defects in a semiconductor or Silicon structure at a rate appropriate to industrial use and in particular enables us to visualise defects in the upper regions of the semiconductor or Silicon structure and in particular near to the surface of same. The technique exploits enhanced non radiative recombination of electron hole pairs at defects in a semiconductor or Silicon structure with a view to enhancing contrast in a PL image of said semiconductor or Silicon structure so as to enhance the viewing of defects in same.

The technique detects and allows high resolution imaging of certain electrically active micro defects on a highly accurate scale. However, it does not detect all relevant defects, since some produce little photoluminescence at room temperature. It does not distinguish between different defects with similar electrical activity, whereas in practice the identity of the particular defect can be critical in deciding whether it will have an unacceptably detrimental effect on the resultant semi-conductor structures.

It is an object of the invention to mitigate some or all of these disadvantages in prior art room temperature PL techniques.

It is a particular object of the invention to develop and adapt prior art room temperature PL techniques and apparatus such as that described above so that effective identification of defects and/or classification of defect types is also made possible.

It is a particular object of the invention to develop room temperature PL

techniques and apparatus exploiting room temperature PL which allow the accurate imaging and characterization of micro-defects in SOI and especially SIMOX and bonded wafers, in polycrystalline Silicon, and in SiGe and like epilayers.

Thus, according to the invention in its broadest aspect, a method for the detection and classification defects in a Silicon or semi-conductor structure comprises:
directing a high intensity beam of light such as a high-intensity laser at a surface of a sample of Silicon or semi-conductor structure to be tested;
producing a first photoluminescence image from photoluminescence produced by excitation of the Silicon or semi-conductor structure by the light beam;
producing a second reflected light image from light reflected from the surface of the Silicon or semi-conductor structure from the light beam;
combining the information in the said two images to detect, map and identify and/or characterise micro-defects in the Silicon or semi-conductor structure.

In its broadest aspect the invention is based on collecting room temperature photoluminescence and reflected laser light image data from a semiconductor or Silicon structure under selected excitation conditions, and then comparing the data to characterise as well as map defects.

When a semiconductor material is excited by above band illumination electrons and holes are generated, recombination back to equilibrium can take place radiatively to produce light (photoluminescence) PL or non-radiatively producing heat. These two processes are in direct competition; in a indirect band material (such as Si) the non-radiative process is faster and more efficient. The non-radiative process is increased by defects and deep level impurities. The

photoluminescence emission process is reduced or quenched at the location of a defect or contaminated region. Focusing a laser beam onto a semiconductor surface and then collecting the PL signal can therefore be used to monitor the presence of defects.

By collecting both the PL and reflected laser light images (surface map=SM) information can be obtained about the defect characteristic and can also be used classify the defect type. This relies on the fact that the response of different defects differs in the two scenarios. In particular the PL technique detects electrically active defects, which may or may not affect reflected laser light intensity, whilst the direct reflected laser image shows defects, which may or may not be electrically active.

Comparison of the results with suitable predetermined reference information about defects or defect types allows the detected defects to be identified or characterised much more accurately than using PL alone to produce results of much enhanced practical value. The two images may be coprocessed to produce a defect map which both locates and characterises the defects for subsequent assessment of their likely detrimental impact on the structure.

Examples of this method are shown in figures 1-3 for Si wafers. In figure 1, the defects only appear in the PL image because they quench the PL signal at the location of the defect and are called electrically active. Such defects will degrade device performance if it is fabricated were the defects are located. The defect observed in figure 2 is a surface scratch it is observed in both the PL and surface map images. Figure 3 shows the image of surface particles which appear on both the PL and SM images.

Combination of the first and second images may be merely by simultaneous observation. Preferably however the images are analysed statistically, for example by digitizing prior to performing a numerical comparison/ analysis.

Preferably, the method involved generating a digitized intensity measurement (e.g. point by point reading but preferably a digitized intensity map) representative of the intensity of the first, PL image; generating a digitized intensity measurement (e.g. point by point reading but preferably a intensity digitized map) representative of the intensity of the second, SM image; numerically comparing the digitized intensity measurements to produce a combined result; comparing the combined result with reference data about defect behavior to characterize the defects detected.

The PL signal generated as a result of laser excitation is given by

$$I = (1 - R)C\int_V A(z)\eta \frac{p(z)}{\tau} dz \qquad [1]$$

where V is the volume of the sample, η is the internal quantum efficiency (τ/τ_{nrad}) and p(z) is the excess carrier density due to optical excitation. C denotes the collection and detector efficiency, and A and R are the correction factors that account for absorption and reflection losses in the sample. The variation in PL intensity recorded in a PL map, reveals variations in η. This can be produced by variations in either the total recombination rate τ, or the radiative rate $\tau_{rad.}$. In general in Si, τ is approximately equal to the non-radiative lifetime τ_{nrad}, and if we assume that as the beam is scanned across a defect, there is a spatial variation in τ_{nrad} only, this will change τ also. Experimentally it has been demonstrated that the PL signal change is directly related to changes

in τ. Therefore the excess carrier distribution at the defect is different to that in the defect free material and defects can thereby be detected.

Photoluminescence is thus collected from the Silicon or semi-conductor structure so as to visualise and observe defects in same by production of an image, in which non-radiative recombination of electron pairs is detected as darkened regions in the image at the physical position of the defect. Reflected laser light is similarly collected from the Silicon or semi-conductor structure so as to visualise and observe defects in same by production of an image in which unreflected light from a defect site is detected as darkened regions in the image at the physical position of the defect.

Certain types of defect can modify the excitation density of electrons and holes produced by the excitation laser, this can be caused by scattering or reflection. This will also lead to a variation in the PL signal (factors A and R in equation 1). Preferably the method correct for this. Preferably a digitized intensity measurement (such as a point by point reading but preferably a digitized intensity map) representative of the intensity of the PL image is generated by applying an appropriate numerical correction factor to collected absolute intensity data to correct for such variations in excitation density before comparison with the SM intensity data.

In the preferred embodiment, a software algorithm is used that corrects the PL image for variations in excitation density. To do this we use the signal variation detected in the SM image to correct the PL image.

This correction takes the ranges of the PL and Surface intensity data and divides the PL range by the SM. This is then multiplied by surface variation from its average value using the standard deviation (s.d) to factorize this

conversion.

The resultant value can then be added to the PL intensity data to give the new PL intensity data for comparison with SM intensity data, and in particular to give a corrected PL intensity map for comparison with the SM map.

$$\left[\frac{PLrange}{SMrange}\times SMs.d\times\left(SM-AveSM\right)\right]+PL$$

Defects are type-characterized or identified by comparing intensity, in particular digitized intensity data from intensity maps, relating to the PL and surface map (in particular the PL data corrected as above and the surface map) and referring to a set of reference data for particular defect types.

High injection level conditions are preferably used in the method of the invention to produce the PL image and defects are detected due to the local change in carrier lifetime at the defect. These defects are typically observed as darkened regions at the physical position of the defect, but in some instances enhanced radiative recombination gives rise to relatively lightened regions, having regard to the background. The recombination at the defects is enhanced by increasing the injection level so that it is not limited by the availability of minority carriers. The preferred PL technique is that in WO97/09649 incorporated herein by reference.

The success of the room temperature PL method disclosed therein is, in part, due to the probing volume of the laser being small, spatial resolution preferably 0.1-20μm, ideally 2-5μm, and with a peak or average power density of between 10^4 - 10^9 watts/cm^2, so that localised defects have much greater effect on the

measured PL intensity and is also believed, in part, because since the excitation is focused the injected carrier density is high. This greatly increases the probability of non-radiated recombination at the defect and hence physical location of the defect. The present invention exploits this, but also applies further imaging information to produce a much more useful overall map of the defects than using PL alone.

Reference herein to a high-intensity laser is meant to include, without limitation, a high power density laser i.e. where regardless of the power of the laser the emittance is focused.

In a preferred method of the invention a pulsed laser excitation source is used and ideally luminescence data is measured and/or the luminescence images collected as a function of time. This means that both depth and spatial resolution are improved and can be used to obtain information on the carrier capture cross sections of the defects. Time resolved measurements can also be used to measure the effective carrier lifetime and obtain lifetime maps.

In a further embodiment of the invention confocal optics are used to obtain depth discrimination of the defects by exciting a large volume of said semiconductor with a laser and collecting images from a series of focal planes.

The method is particularly effective when applied in detecting imaging and characterising near surface micro-defects in SOI and especially SIMOX and bonded wafers, in polycrystalline Silicon, and in SiGe and like epilayers.

Digitization of image intensity information and/or application of correction factors to PL image data and/or numerical comparison of digitised PL and SM

image data and/or comparison of the results thereof with reference data may be implemented by suitable computer software.

According to further aspects, the invention comprises computer software to implement the said method steps of digitization of image intensity information and/or application of correction factors to PL image data and/or numerical comparison of digitised PL and SM image data and/or comparison of the results thereof with reference data; such software on a suitable data carrier, said data carrier optionally further incorporating said reference data; and a suitably programmed computer programmed with such software and optionally further programmed with said reference data.

According to a further aspect of the invention there is provided an apparatus for undertaking photoluminescence imaging of a semiconductor or Silicon structure simultaneously or consecutively with reflected light imaging to perform the above method.

The apparatus comprises a high intensity light beam source such as a high-intensity laser directable at a surface of a sample of Silicon or semi-conductor structure to be tested; a first imaging means to produce a first image from photoluminescence produced by excitation of the Silicon or semi-conductor structure by the light beam; a second imaging means to produce a second reflected light image from light reflected from the surface of the Silicon or semi-conductor structure; means to enable comparison of the two images.

The imaging means may simply be displays (direct screen, photographic, camera and screen etc) allowing simultaneous viewing by an observer. Additionally or alternatively, digital imagers such as digital cameras collect

digitised image intensity data to be processed numerically as above described.

The apparatus preferably further comprises means to process digitised image intensity data. In particular it further comprises a first data register to store digitised image intensity data from PL imaging, a second data register to store digitised image intensity data from RL imaging, a reference register containing intensity data characteristic of defect type, optionally a data corrector to apply correction to data in the first register using data in the second register as above described, an image comaparator to combine data from the first and second registers to produce a combined result and to compare the a combined result with data in the reference register to characterise defects, a display to display the detected and characterised defect results.

In a preferred embodiment of the invention the laser is modulatable so as to adjust the wavelength excitation of same thereby enabling a user of said apparatus to sample said semiconductor or Silicon structure at different depths. For example, a short wavelength may be used to sample near the surface of the said semiconductor or structure and a longer wavelength to look deeper into the semiconductor or structure.

In yet a further preferred embodiment of the invention the apparatus is provided with means to enable pulsing of said laser and ideally also for PL images to be obtained as a function of time.

In a yet further preferred embodiment of the invention said apparatus is provided with means for modulating said laser at high frequencies (0.1-100 MHz) thereby enabling a user of said apparatus to sample said semiconductor or Silicon structure at different depths.

In yet a further preferred embodiment of the invention said apparatus comprises a laser of a spot size of between 0.1mm and 0.5 microns and/or a power density of between 10^4 to 10^9 watts/cm^2.

In yet a further preferred embodiment of the invention the apparatus comprises confocal optics which is used to obtain depth discrimination of the defects by exciting a large volume of said semiconductor with a laser and collecting images from a series of focal planes.

According to a further aspect the invention comprises PL and SM images and/or PL and SM digitised intensity maps of a silicon or semi-conductor structure generated in viewable and/or digitally processable form by the foregoing method or using the foregoing apparatus and suitable for comparison to detect, map and identify and/or characterise micro-defects in the silicon or semi-conductor structure.

The invention is illustrated with reference to Figures 1 to 8 of the accompnaying drawings in which:

Figure 1 shows PL and surface maps produced in accordance with the invention illustrating electrically active defects;

Figure 2 shows PL and surface maps produced in accordance with the invention illustrating a surface scratch;

Figure 3 shows PL and surface maps produced in accordance with the invention illustrating surface particles;

Figure 4 shows TEM cross-section micrographs showing a) Silicon bridges, b) and Si inclusions;

Figure 5 shows PL and surface maps produced in accordance with the invention illustrating a SIMOX wafer containing Si bridging defects;

Figure 6 shows PL and surface maps produced in accordance with the invention illustrating a SIMOX wafer containing Si inclusions;

Figure 7 shows PL and surface maps produced in accordance with the invention illustrating SOI void defect in bonded wafers;

Figures 8 and 9 show PL and surface maps produced in accordance with the invention illustrating defects in polycrystalline Si;

Figure 10 shows PL and surface maps produced in accordance with the invention illustrating defects in SiGe epilayer.

Figures 1 to 3 show silicon wafers. In figure 1, the defects only appear in the PL image because they quench the PL signal at the location of the defect and are called electrically active. Such defects will degrade device performance if it is fabricated were the defects are located. The defect observed in figure 2 is a surface scratch it is observed in both the PL and surface map images. Figure 3 shows the image of surface particles which appear on both the PL and surface map.

PL maps have been measured on Silicon-on-insulator (SOI) fabricated using

separation by implantation of oxygen (SIMOX). To illustrate the usefulness of this method wafers were produced deliberately to have specific defect type in SIMOX, Silicon bridges and Silicon inclusions in the buried oxide part of the structure (BOX). High-resolution transmission electron microscopy (TEM) was used to identify the different defects. Figure 4a shows a cross section TEM image representative of the defects detected in the sample with Si bridges. The sample containing Si inclusions is shown in Figure 4b.

The PL image of the sample containing Si bridges is shown in figure 5, after software correction. The individual defects are detected as small localized areas of reduced PL intensity, each black spot corresponding to a Si bridge defect. The PL image from the sample containing Si inclusions shows localized areas of increased PL intensity. Each individual defect relating to a Si inclusion. After acquiring the PL image from these well known defect types and correcting the PL image it is now possible to classify the defect type by the effect on the PL signal at the defect. Thereby allowing classification and enabling defect detection.

This software procedure can be applied to other defects detected in SOI structures. For SOI wafers fabricated using direct wafer bonding, defects can be formed were the wafers do not bond are termed voids. An example of this type of void defect detected by PL is shown in figure 6. The PL image is corrected and different type of void defects can be classified. These voids can be produced by particles, surface roughness or contmaintion.

Polycrystalline Si contains grain boundaries (is the boundary between two crystal regions of different orientation) which are physical defects on the sample surface these defects will also have electrical activity, to remove the physical

effect of the boundary we have applied the software correction model to correct the PL images the results are shown in Figures 7 and 8. This allows the electrically nature of the grain boundaries and inter-grain defects to be assessed and classified.

Defects can also be detected in SiGe epilayers; a PL map of a typical defect is shown in figure 9. Clearly, again the software correction can be used to facilitate classification of the defect type.

The application of PL mapping coupled together with the reflected surface map can be used for correcting the PL image to reveal the true electrical activity and enables defect classification.

CLAIMS

1. A method for the detection and classification defects in a silicon or semi-conductor structure comprising the steps of:
directing a high intensity beam of light at a surface of a sample of silicon or semi-conductor structure to be tested;
producing a first photoluminescence image from photoluminescence produced by excitation of the silicon or semi-conductor structure by the light beam;
producing a second reflected light image from light reflected from the surface of the silicon or semi-conductor structure from the light beam;
combining the information in the said two images to detect, map and identify and/or characterise micro-defects in the silicon or semi-conductor structure.

2. The method of claim 1 wherein the photoluminescence and reflected laser light image data are compared with suitable predetermined reference information about defects or defect types whereby the detected defects are both mapped spatially and identified or characterised.

3. The method of claim 2 wherein the two images are coprocessed to produce a defect map which both locates and characterises the defects for subsequent assessment of their likely detrimental impact on the structure.

4. The method of any preceding claim wherein combination of the first and second images is performed in that the images are analysed statistically

by digitizing prior to performing a numerical comparison/ analysis.

5. The method of claim 4 wherein the combination analysis comprises the steps of generating a digitized intensity measurement representative of the intensity of the first, PL image; generating a digitized intensity measurement representative of the intensity of the second, SM image; numerically comparing the digitized intensity measurements to produce a combined result; comparing the combined result with reference data about defect behavior to characterize the defects detected.

6. The method of claim 5 wherein one or both of the generated digitized intensity measurements is produced as a intensity digitized spatial map.

7. The method of claim 5 or claim 6 further comprising correcting the PL digitized intensity measurement for excitation density modification associated with certain defects by applying an appropriate numerical correction factor to collected absolute intensity data to correct for such variations in excitation density before comparison with the SM digitized intensity measurement data.

8. The method of claim 7 wherein a software algorithm is used to correct the PL image for variations in excitation density.

9. The method of claim 7 or claim 8 wherein correction is effected by evaluating the measured intensity ranges of the PL and Surface maps, dividing the PL range by the SM range, multiplying this result by surface variation from its average value using the standard deviation (s.d) to factorize this conversion, adding the resultant value to the collected

absolute PL intensity data to give new PL intensity data.

10. The method of any preceding claim comprising directing a high-intensity laser at a surface of the sample at room temperature.

11. The method of claim 10 wherein the probing volume of the laser is small, spatial resolution being between 0.1-20μm.

12. The method of claim 11 wherein the ideally spatial resolution is between 2 and 5μm.

13. The method of claim 11 or claim 12 wherein the peak or average power density is between 10^4 - 10^9 watts/cm^2

14. The method of any preceding claim wherein a pulsed laser excitation source is used and luminescence data is measured and/or the luminescence images collected as a function of time.

15. The method of any preceding claim wherein confocal optics are used to obtain depth discrimination of the defects by exciting a large volume of said semiconductor with a laser and collecting images from a series of focal planes.

16. The method of any preceding claim wherein digitization of image intensity information and/or application of correction factors to PL image data and/or numerical comparison of digitised PL and SM image data and/or comparison of the results thereof with reference data may be implemented by suitable computer software.

17. Computer software to implement the method of claim 16 by performing one or more of the said method steps of digitization of image intensity information and/or application of correction factors to PL image data and/or numerical comparison of digitised PL and SM image data and/or comparison of the results thereof with reference data.

18. A data carrier carrying software in accordance with claim 17 for performing at least the step of numerical comparison of digitised PL and SM image data and comparison of the results thereof with reference data in executable form, and further carrying such reference data in a readable form.

19. An apparatus for undertaking photoluminescence imaging of a semiconductor or silicon structure simultaneously or consecutively with reflected light imaging comprising a high intensity light beam source such as a high-intensity laser directable at a surface of a sample of Silicon or semi-conductor structure to be tested; a first imaging means to produce a first image from photoluminescence produced by excitation of the Silicon or semi-conductor structure by the light beam; a second imaging means to produce a second reflected light image from light reflected from the surface of the Silicon or semi-conductor structure; means to enable comparison of the two images.

20. An apparatus in accordance with claim 19 wherein the imaging means are displays allowing simultaneous viewing by an observer.

21. An apparatus in accordance with claim 19 or 20 wherein the imaging

means comprise digital imagers adapted to collect digitised image intensity data to be processed numerically, and the apparatus further comprises means to process digitised image intensity data in the form of a first data register to store digitised image intensity data from PL imaging, a second data register to store digitised image intensity data from RL imaging, a reference register containing intensity data characteristic of defect type, optionally a data corrector to apply image correction to data in the first register, an image comaparator to combine data from the first and second registers to produce a combined result and to compare the a combined result with data in the reference register to characterise defects, a display to display the detected and characterised defect results.

22. Apparatus in accordance with one of claims 19 to 21 provided with means to enable pulsing of said laser and thereby obtain PL images to be obtained as a function of time.

23. Apparatus in accordance with one of claims 19 to 22 provided with a modulatable laser and control means for modulating said laser at high frequencies (0.1-100 MHz) thereby enabling a user of said apparatus to sample said semiconductor or Silicon structure at different depths.

24. PL and SM images and/or PL and SM digitised intensity maps of a silicon or semi-conductor structure generated in viewable and/or digitally processable form by the method of one of claims 1 to 16 or using the apparatus of one of claims 19 to 23

Figure 1

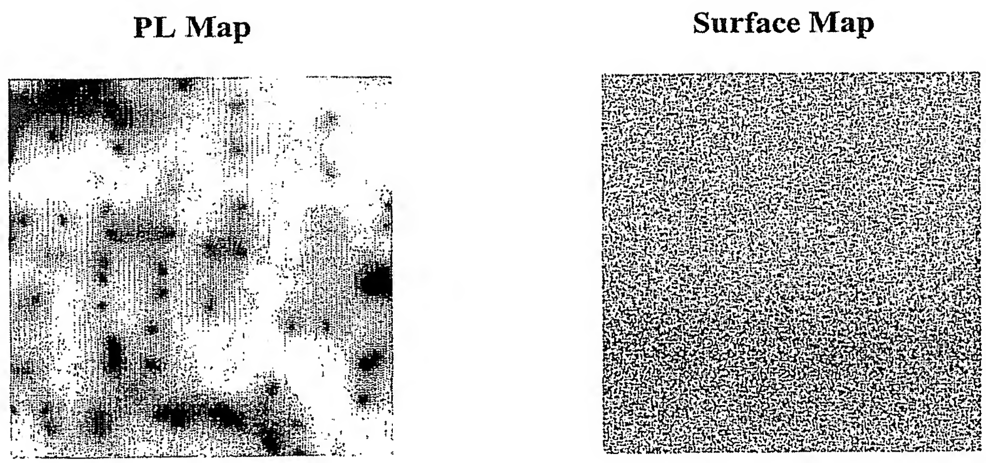


Figure 2

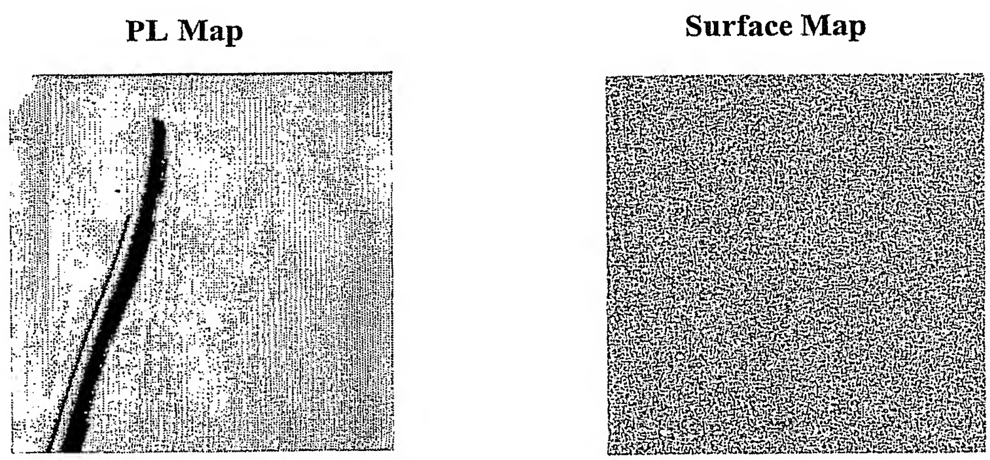


Figure 3

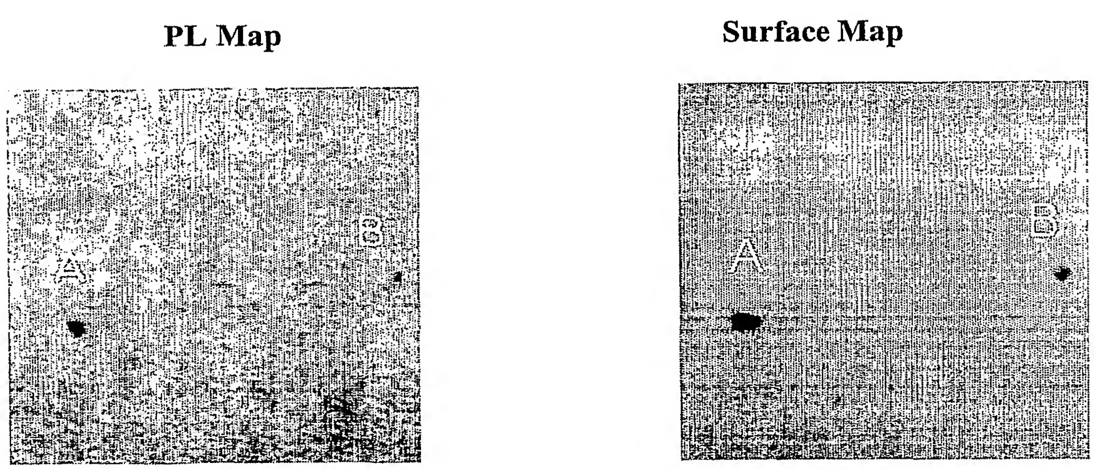


Figure 4

a) b)

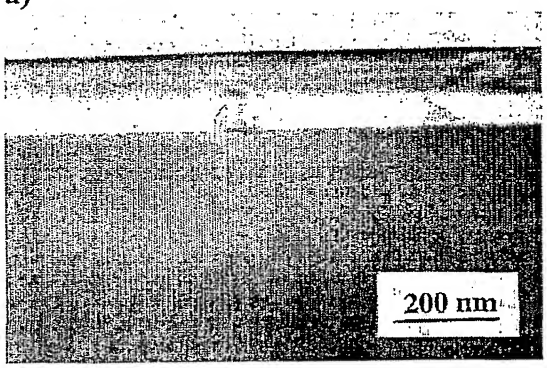


Figure 5

PL Map Surface Map

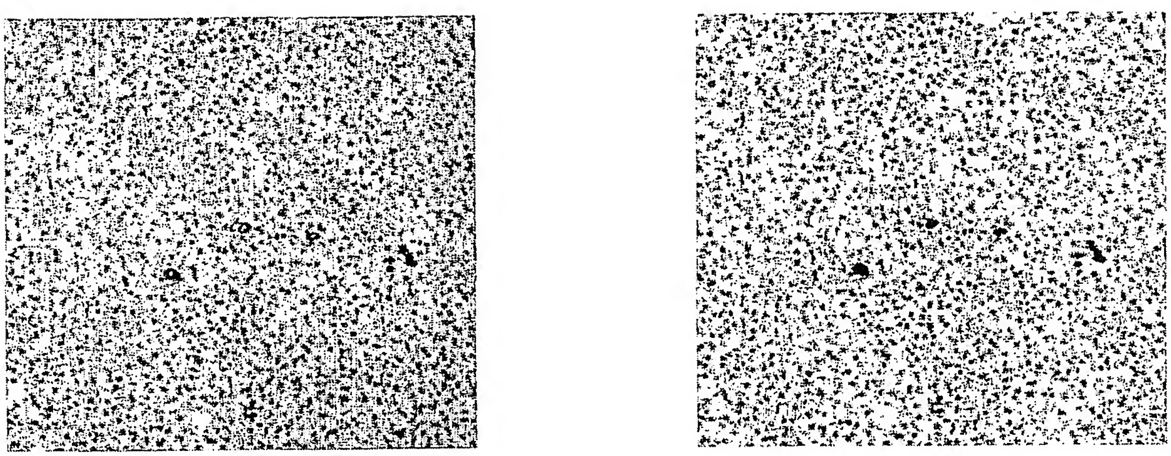
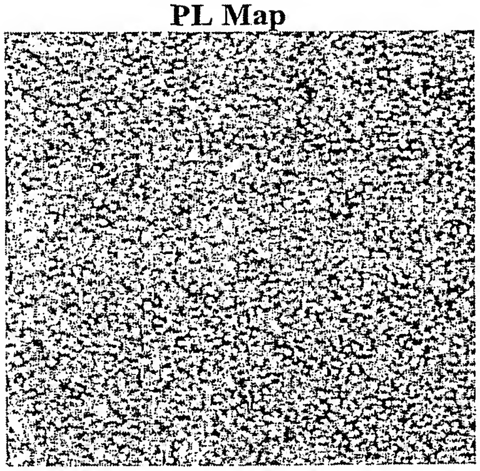


Figure 6

PL Map



Surface Map

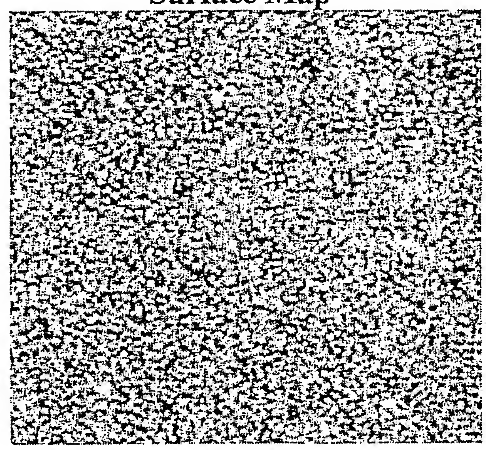
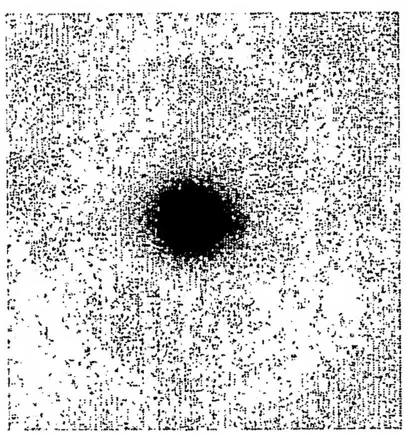


Figure 7

PL Map



Surface Map

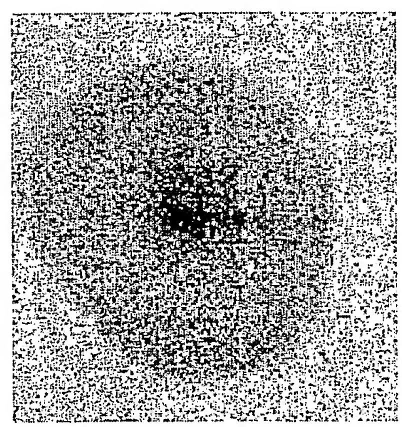
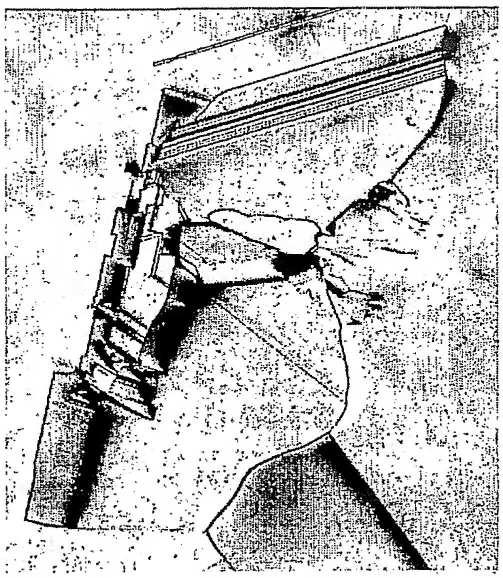


Figure 8

PL Map



Surface Map

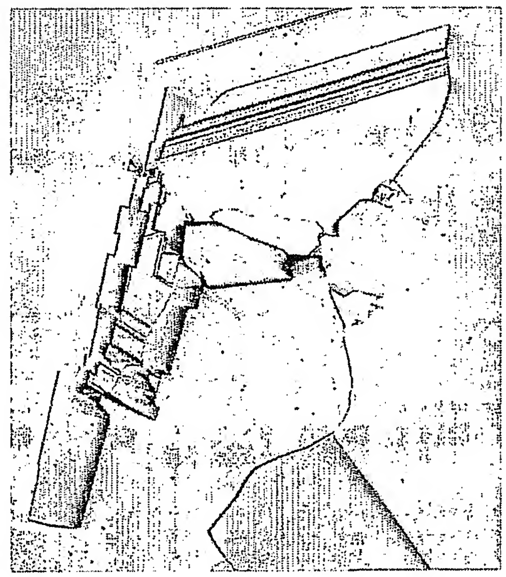
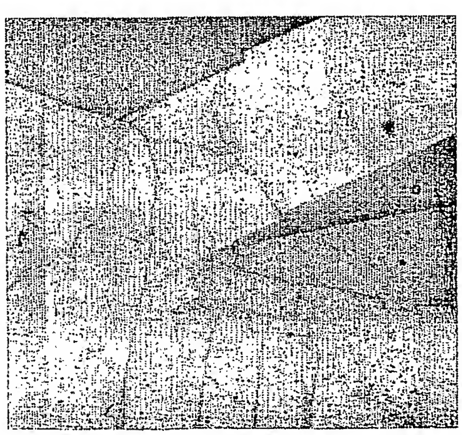


Figure 9

PL Map



Surface Map

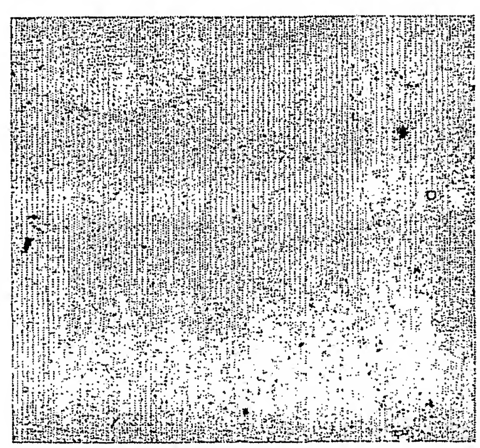
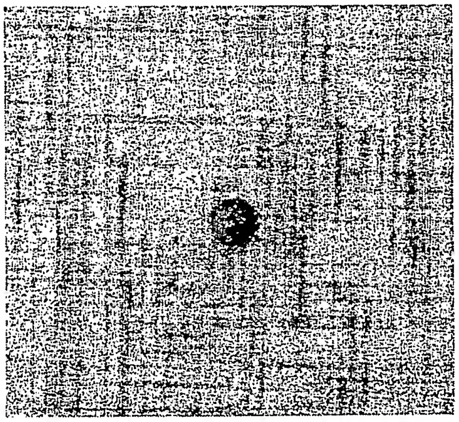
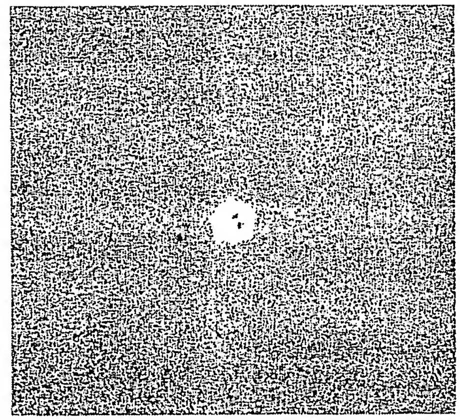


Figure 10





INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 02/01197

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01N21/64 G01N21/55 G01N21/95

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	HIGGS V ET AL: "Application of room temperature photoluminescence for the characterization of impurities and defects in silicon" PROCEEDINGS OF THE SPIE, SPIE, BELLINGHAM, VA, US, vol. 3895, 13 September 1999 (1999-09-13), pages 21-37, XP002187098	1-6, 10-12, 16,19-22
Y	the whole document --- -/--	13-15,23

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 July 2002	05/08/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Meyer, F

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	RIBES A C ET AL: "Reflected-light, photoluminescence and OBIC imaging of solar cells using a confocal scanning laser MACROscope/microscope" SOLAR ENERGY MATERIALS AND SOLAR CELLS, ELSEVIER SCIENCE PUBLISHERS, AMSTERDAM, NL, vol. 44, no. 4, 15 December 1996 (1996-12-15), pages 439-450, XP004065716 ISSN: 0927-0248	1,3,6, 11,12, 15,16, 19-21
Y	page 439-444	13,14, 22,23
	page 450; figures 5A,B	
P,X	BOTHE K ET AL: "Spatially resolved photoluminescence measurements on Cu(In,Ga)Se2 thin films" PREPARATION AND CHARACTERIZATION, ELSEVIER SEQUOIA, NL, vol. 403-404, 1 February 2002 (2002-02-01), pages 453-456, XP004334538 ISSN: 0040-6090 the whole document	1,4,6, 11,12, 19,20,22
Y	WO 98 11425 A (BIO RAD MICROMEASUREMENTS LTD ;MAYES IAN CHRISTOPHER (GB); HIGGS V) 19 March 1998 (1998-03-19) abstract page 6, paragraph 5 -page 10, paragraph 1 page 11, paragraph 5 -page 16, paragraph 2 figures 7-9	13-15, 22,23

INTERNATIONAL SEARCH REPORT

rnational application No.
PCT/GB 02/01197

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 24
because they relate to subject matter not required to be searched by this Authority, namely:

Rule 39.1(v) PCT - Presentation of information

2. [X] Claims Nos.: 17,18,24
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

see FURTHER INFORMATION sheet PCT/ISA/210

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box I.2

Claims Nos.: 17,18,24

The phrase in claim 17 "... software to implement the method of claim 16 by performing ..." is incomprehensible. It appears that any operating system would be capable of "implementing" the said method steps.
It is furthermore not clear which of the method steps defined in the preceding claims, in particular defined in claim 1, are to be controlled ("performed") by said software. It may be doubted, due to the formulation "... by performing one or more of the said method steps ...", whether it is actually intended that the claimed software carries out the method steps as defined in claim 1.
Due to the use of the wording "and/or" in claim 17, the said claim covers 8 different alternatives, but which multiplicity of alternatives even further renders it unduly burdensome to determine the matter for which protection is sought (see the PCT Guidelines III 5.).
Finally, in the case of an "or"-combination, it is not clear what is meant by "comparison of the results thereof with ...".

Claim 18 is unclear since it refers to claim 17. Here, again (see above), it is not at all clear which of the method steps defined in the preceding claims, in particular defined in claim 1, are to be controlled ("performed") by said software on said data carrier.
Claim 18 claims a "data carrier carrying software ... and further carrying ... reference data" whereas in the description (see p.12 2 1.6) said "reference data" is stated to be incorporated optionally. This inconsistency renders the scope of said claim for which protection is sought even further unclear.

Claim 24 appears to describe merely the presentation of information for which no international search has to be carried out (see Rule 39.1(v) PCT).
Besides this, the subject-matter for which protection was sought would not be clear. Said claimed image(s)/map(s) could be any array(s) of numbers or any arrangement of electrons (or charges) in the memory of a computer ("in ... digitally processable form").
The claimed subject-matter would furthermore be indefinite because the claim refers to a "silicon or semi-conductor structure" but which "structure" has not been defined.
It would also not be clear in which way use of the method of claim 1 or of the apparatus of claim 19 would result in images different to any image produced by known methods or apparatus.
Finally, it would not clear what was meant by the abbreviation "SM images / maps".

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

INTERNATIONAL SEARCH REPORT

Information on patent family members

onal Application No
PCT/GB 02/01197

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 9811425	A	19-03-1998	AU	4126997	A	02-04-1998
			EP	0925497	A1	30-06-1999
			WO	9811425	A1	19-03-1998
			JP	2001500613	T	16-01-2001